DATA ACQUISITION, CONTROL, AND SPECTRAL ANALYSIS SOFTWARE FOR MULTI-CHANNEL ANALYZERS

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention is related to the field of radioactive source identification and, more particularly, to a device for detecting and identifying low-level radioactive sources moving past stationary detectors.

Description of the Related Art

According to the prior art, detection of radioactive sources has not been accomplished at full highway speeds, a scenario known as drive-by or pass-by detection, and certainly real-time identification of sources at these speeds has not been possible. By contrast, most nuclear radiation detection is done using a detector and source that are both stationary.

Since, due to source speed, the interaction time of the radioactive source with the detector is short in a drive-by detection scenario, detector counting time must also be short. This leads to many counting intervals each second. In order for the system to be sensitive, it must be capable of reacting to a small number of counts. However, if the system reacts to a small number of counts, it is possible that normal background fluctuations may activate the system. The high frequency of the time slices thus forces the threshold of the system to be high, to keep the false alarm rate low, but a high threshold is inconsistent with sensitivity to a low count source. Therefore, a need exists for a system that is able to detect radioactive sources moving at highway speeds, having high sensitivity coupled with substantial resistance to false alarms.

SUMMARY OF THE INVENTION

In view of the foregoing, one object of the present invention is to overcome the difficulties associated with detection of low-level radiation sources in drive-by or pass-by detection scenarios.

Another object of the present invention is to provide a detector that counts in small time slices on the order of one eighth of a second to accommodate the high speed of the source.

A further object of the present invention is to provide a detector that uses the differences between source counts and background counts to distinguish between the two, providing the high sensitivity with low false alarm rate needed for such a system to be useful.

In accordance with these and other objects, the present invention is directed to a method for detecting and identifying low-level radioactive sources moving past at least two stationary detectors by comparing stored background spectra representing an expected number of counts over one or more time slices in one or more channels for each of the detectors with currently received spectra in a corresponding time period and channel range for each detector. A probability that the number of counts received by each of the detectors is attributable to background is calculated and, depending upon the relationship of the two probabilities to each other and to a threshold value, it is determined whether or not the source of the counts is a radioactive source.

These together with other objects and advantages which will become subsequently apparent reside in the details of construction and operation as more fully hereinafter described and claimed, reference being had to the accompanying drawings forming a part hereof, wherein like numerals refer to like parts throughout.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of the hardware for a detector system in accordance with the present invention;

Figure 2 illustrates a representative photopeak for radioactive cesium (^{137}Cs);

Figure 3 is a graph of an expected number of background counts in a 0.125 second time slice ($r_i\tau$);

Figure 4 is a graph of the counts required to exceed probability levels in a single detector, single time slice; and

Figure 5 is a flowchart of the hit detection process.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In describing a preferred embodiment of the invention illustrated in the drawings, specific terminology will be resorted to for the sake of clarity. However, the invention is not intended to be limited to the specific terms so selected, and it is to be understood that each specific term includes all technical equivalents which operate in a similar manner to accomplish a similar purpose.

As shown in Figure 1, the system includes two or more NaI(Tl) detectors 10, each including a sodium iodide (NaI) crystal with an associated photomultiplier tube (PMT) and electronics. The NaI crystals are sensitive to gamma rays from a radioactive source, producing a flash of light in response to absorption of these rays which is detected and processed by the PMT and electronics for further processing by a respective one of a plurality of multichannel analyzers 20 which are, in turn, coupled to an internal memory 30 within a control computer 40. Each multichannel analyzer (MCA) 20 provides the energy vs. count distribution for a respectively connected NaI detector 10. As the potential interaction time is very short (~.2-.3 seconds), the MCA must acquire data in very small time slices (~0.1-0.125 seconds). For the hit determination algorithm to work optimally, the acquisition time slices must be about one-third to one-half of the smallest expected interaction time.

In the short interaction time used, the relative fluctuations of counts in any given channel may be quite large. However, as there are certain indicators that typically accompany source versus background counts, the spectra obtained from the MCA's are checked for events that are not likely to have come from background fluctuations.

Background fluctuations have three main characteristics that are important to the effective operation of the system according to the present invention. First, background counts are not correlated with respect to channel numbers. Therefore, if there is a count in channel i, there is no greater probability of a count appearing in channel i-1 or channel i+1. Second, background counts are not correlated with respect to time slice; if there is a count in channel i during time slice j, then there is no greater probability of a count appearing in time slice j-1 or j+1. Third, background counts are not correlated with respect to detector such that, if there is a count in channel i of detector 1, there is no greater probability of there being a count in channel i of detector 2.

Counts from sources follow different patterns from those demonstrated by background counts. Particularly, counts from sources tend to group around the source photopeak such that there exists a channel or group of channels where source counts are more likely to occur, depending on the γ energy of the source. As previously noted, the NaI detectors produce a flash of light in response to gamma ray absorption. For gamma rays that have all of their energy converted to light, i.e., they are completely absorbed, the MCA puts those counts into a few channels which represent the photopeak for that source, while gamma rays that are not completely converted to light occur in what is known by those of skill in the art as the Compton Continuum; a representative photopeak and Compton Continuum for a cesium source(^{137}Cs) is shown in Figure 2.

Next, source counts arrive only during time slices during which the source was close to the detector. Thus, if for two to three time slices there are counts in channel i during time slice j, there will be a greater probability of counts occurring during time slice j-1 or j+1 if the counts arise from a radioactive source.

Finally, source counts are correlated with respect to detector; if counts from a source occur in channel i of detector 1, there is a greater probability of counts occurring in channel i of detector 2, assuming proper calibration of the two detectors.

Accordingly, the analysis algorithm according to the present invention looks for the correlations that are unique to source counts. When events with a high degree of correlation consistent with source counts appear, they are counted as a source. The power of the technique is that the probability of the predictable patterns caused by γ ray sources occurring as a result of background fluctuations is so small as to be virtually non-existent.

Analysis Algorithm

In a given channel, the mean number of counts expected from the background during a time slice is given by Poisson statistics

$$P_i(n)=(r_i\tau)^n\exp(-r_i\tau)/n!, \qquad \text{Equation 1}$$

where $P_i(n)$ is the probability of obtaining n counts in channel i, r_i is the background rate of channel i, τ is the counting or acquisition time of the time slice, and n is the

number of counts in channel i. With the value of $r_i\tau$ representing the background spectra, the hit detection algorithm takes the number of counts in a channel and calculates the probability that the counts came from the background. If the probability is below a threshold, it is assumed that the counts did not come from background fluctuation, that is, the counts came from a nearby radioactive source.

For illustration, the background shown in Figure 3 was accumulated over 1000 seconds, and scaled to give the expected number of counts in a 0.125 second time slice. For this particular detector, at this particular time, the expected number of background counts in a 0.125 second time slice is less than one in all channels; these are the values of $r_i\tau$ used in Equation 1. A spectrum is checked by using the actual number of counts that occurred in each channel during the time slice (n in Equation 1). If the probability that the fluctuation is due to background is sufficiently small, a hit is considered to have occurred. The number of counts required to exceed various probability levels is shown in Figure 4.

Simply obtaining counts above a predetermined threshold level in a channel is not sufficient to qualify an event, however. There must also be counts in the other detector in the same channel. This is because background counts are not correlated across the detectors. Only sources give counts simultaneously in both detectors. Comparing the counts of two or more detectors, and noting as a source only those instances in which both detectors register counts, is one of the main ways in which false alarms due to background fluctuations are reduced. In this way, the required count threshold for a single detector can be set quite low, while still yielding a low rate of false alarm.

The sensitivity of the system is increased by using correlations across time slices and across the energy spectra. As previously identified, background counts do not correlate from one time slice to the next. Instead, the time correlations are seen only while a radioactive source is passing in front of the detector. Events with a low probability due to background fluctuations that repeat from time slice to time slice are a unique signature of a passing radioactive source.

Finally, most photopeaks occur in more than one channel. When a source is present, the counts over a region of channels or energy bins increases. This is another signature unique to radioactive sources. Furthermore, the width of a peak varies with channel number. The larger the bin or channel number, the wider the peak. The analysis program of the present

invention looks for anomalous numbers of counts over regions consistent with the width of a predicted source photopeak.

Basic Implementation

Background spectrum is first obtained for the 256 channels in the spectrum and recorded over some period of time, typically 1000 seconds, as was undertaken to obtain the background in Figure 3. At 1000 seconds of counting time there is a low probability that there will be zero counts in a channel, i.e., that r_i will be zero. The average number of counts that could be expected per second is then found by dividing each channel by the 1000 second acquisition time. The Poisson formula is written in natural log form as

$$-\ln(P_i(n))=r_i\tau+\ln(n!)-n(\ln(r_i)+\ln(\tau)) \qquad \text{Equation 2}$$

Given the small probabilities being used, this implementation reduces round off errors and provides values that are more easily implemented. As the formula uses the natural log of the scattering rate, a value of zero for r_i must be avoided. The long background acquisition time (1000 seconds) helps to avoid this pathological situation. Also, the program checks for a value of zero in background bins. Any bin with a zero is changed to a value of one. Since the acquisition time τ actually varies slightly from time slice to time slice, this number is measured and the actual acquisition time is used in the calculation.

The average scattering or background rate r_i is contained in a 256 element array, as is the $\ln(r_i)$. The natural logs of n! from 0-50 are also pre-computed, and stored in an array. Values of n greater than 50 use ln(50!) . At the highest background rate, the peak number of counts expected in a time slice is a little greater than one, and the probability of more than 50 counts occurring due to background alone is so low as to be meaningless. The negative of the natural log is used to make hits appear as positive numbers. The probability values for a 256 channel spectrum can be calculated in about 50 τs. In the two-detector system, there are 50 ms of time within which to do the hit calculations, so with the current algorithm there are no calculation time issues.

Counts from the photopeak usually occur over a number of channels. The width of the peak increases with increasing channel number. Because of this, the value of r_i is actually

the mean number of counts expected over a number of adjacent channels, with the number of adjacent channels corresponding with the expected width of the photopeak. The number of channels to be summed, i.e., the width of the window, for the current spectra corresponds with the width of the window taken when determining the background or scattering rate. This number of channels used in the sum is shown in Table 1.

Figure 5 provides a conceptual overview of the hit detection process. Background spectra (μ_n) is stored for each detector, step 70, with μ_n being the average number of counts over the number of channels constituting the expected photopeak width. Spectra from each detector is then collected, step 72, and the probability of the counts from each channel having resulted from background is computed, step 74, using the following formula,

$$P_n = (\mu_n)^c \exp(-\mu_n)/c! \qquad \text{Equation 3}$$

where c is the number of counts from the current spectra over the same number of channels used to obtain μ_n. Spectra determined to exceed a probability threshold in corresponding channels of the two detectors, step 76, is identified as a "hit" arising from a radioactive source, step 78. Spectra which does not demonstrate this correlation is added to the background spectra, step 80, whether for the first detector 70a or the second detector 70b.

The process of Figure 5 may be repeated for spectra from consecutive time slices to identify those spectra also showing correlation across two or more sequential time slices, with the probabilities from multiple time slices being summed and compared with threshold values to determine whether or not the spectra represents a hit.

For channels 0-25, the calculated probability is based on one channel and two time slices. This means -ln(Pi) from the preceding time slice is added to the present probability. The previous two time slices for the second detector are also summed and, if the count probability from each detector is above some minimum threshold, the event is classified as a radioactive source.

Alternatively, in considering multiple time slices, the probability 74a obtained from two slices with the first detector 72a may be added to the probability 74b for the corresponding two time slices for the second detector 72b, and if the resulting sum is above a threshold, the event is classified as a radioactive source provided that the count probability from

each detector is also above some minimum threshold. This reduces the probability that a large background fluctuation in one detector could be mistaken for a radioactive source. If the event passes both of these tests, it is considered to be caused by a passing source.

Table 1. Summing width as a function of channel number

Channel Numbers	Number of summed channels
0-25	1 (i)
26-75	3 (i +/-1)
76-125	5 (i +/-2)
126-175	7 (i +/-3)
176-250	9 (i +/-4)

The calculations are similar for energy bins greater than channel 25. However, because the photopeaks are spreading with higher channel numbers, the number of channels over which the probabilities must be summed increases. For channels 26-75, the probability for channel i is calculated by summing counts over three channels. The number of channels used in the sum is determined by measuring the e^{-1} peak width as a function of peak channel number. The same time steps taken with regard to time slice and detector are then performed with this probability.

A spectrum is analyzed for a hit by using Equation 2. The probability that the number of counts over the channels occurred due to background is calculated. This probability of occurrence vs. channel number is summed with the natural log of the probabilities from the previous time slice. Since a source is expected to be in the field of view for at least two time slices, counts from sources should be elevated over two adjacent time slices. This is compared with the probability vs. channel number of the other detector. Currently, if either of the detectors has a channel with probability due to background of less than 10^{-9}, or if both detectors have a channel (the same channel in each detector) with a probability of less than 10^{-6}, the event is counted as a radioactive source. These numbers have not been optimized with respect to sensitivity and false alarm rate. The values were sufficient for the sources used in system demonstrations.

System sensitivity can be estimated from Figure 4. With the current threshold values used (both detectors must be showing a two-time slice probability of 10^{-6}) the number of counts required as a function of channel can be calculated. For lower energy channels (channels 0-25) with higher background rates, about three to four counts/time slice must be reported from each detector in order for the event to be counted as a radioactive source. Higher energy channels, with lower backgrounds, will be reported as a hit if one or two counts/time slice are observed in each detector, in the same energy bin.

The system described herein applies to other radiation detectors using a multi-channel analyzer, such as cesium iodide (CsI) and high-purity germanium (HPGe) detectors. In the case of detectors capable of high spectral resolution, such as HPGe, the software would be required to operate with a larger number of channels in many applications. This change is a straightforward extension of the current system.

The foregoing descriptions and drawings should be considered as illustrative only of the principles of the invention. The invention may be otherwise configured and is not limited to the configurations of the preferred embodiment. Numerous applications of the present invention will readily occur to those skilled in the art. Therefore, it is not desired to limit the invention to the specific examples disclosed or the exact construction and operation shown and described. Rather, all suitable modifications and equivalents may be resorted to, falling within the scope of the invention.